Advanced Underground Vehicle Power and Control Fuel Cell Mine Locomotive

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Objectives

- Develop a zero-emissions, fuel cell powered metal-mining locomotive
- Evaluate its safety and performance, primarily in surface tests
- Evaluate its productivity in an underground mine in Canada

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- A. Vehicles
- B. Storage

Approach

- Design 14 kW fuel cell powerplant
- Design metal-hydride storage
- Integrate powerplant and hydride storage onto locomotive base vehicle
- Conduct preliminary tests and evaluate
- Refine final design
- Perform safety and risk analysis and complete documentation to meet regulatory approval
- Evaluate productivity performance in an underground metal mine

Accomplishments

- Designed 17 kW fuel cell powerplant and metal-hydride storage
- Integrated powerplant and metal-hydride storage onto locomotive base vehicle
- Performed preliminary testing and evaluation in Nevada
- Completed safety and risk assessment

- Completed documentation for regulatory approval
- Tested and evaluated productivity performance in an underground metal mine

Future Directions

- Project successfully completed and closed out January 2003

Introduction

Underground mining is the most promising application in which fuel cell vehicles can compete strictly on economic merit (1). The mining industry, one of the most regulated, faces economic losses resulting from the health and safety deficiencies of conventional underground traction power. Conventional power technologies - tethered (including trolley), diesel, and battery - are not simultaneously clean, safe, and productive. Solution of this problem by fuel cells would provide powerful cost offsets to their current high capital cost. Lower recurring costs, reduced ventilation costs, and higher vehicle productivity could make the fuel cell vehicle cost-competitive several years before surface applications. The fuel cell locomotive is shown in Figure 1.

Approach

A joint venture between the Fuelcell Propulsion Institute (a nonprofit consortium of industry participants) and Vehicle Projects LLC (project management) provided the basis for the 2-phase project. In Phase 1, Sandia National Laboratories was tasked with the design of the fuel cell powerplant and the metal-hydride storage, as well as system integration. Phase 2 included system evaluation, safety and risk assessment, and underground testing in a production environment.

Figure 1. Fuel Cell Mine Locomotive

To ensure the locomotive was designed with industry in mind, various industry participants were involved to assess the design for risk and functionality. When the locomotive was tested underground, all regulatory requirements were met.

Results

The locomotive's fuel cell power system uses proton exchange membrane (PEM) fuel cells. No traction battery is employed, and the vehicle is thus a pure fuel cell vehicle. Two stacks in electrical series provide 126 V and 135 A at the continuous rated power of 17 kW gross. Parasitic losses are less than 10%, a very good performance result. Waste heat from the stacks provides the heat to desorb hydrogen from the metal-hydride bed. A heat exchanger links the two isolated thermal systems: (a) the hydride-bed heating/cooling loop and (b) the stack cooling loop. Figure 2 depicts the schematic layout of the powerplant and metal-hydride storage. Specifications of the fuel cell and battery versions of the locomotive are compared in Table 1.

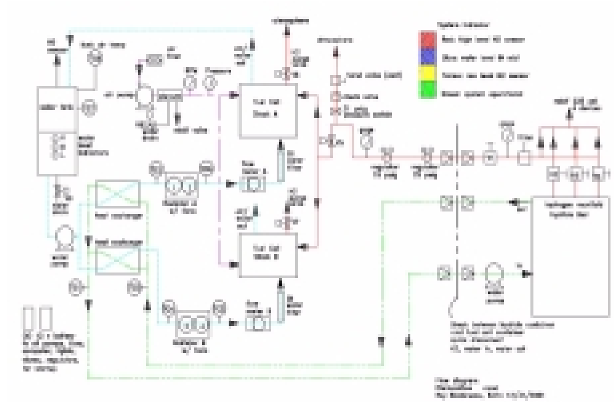

Figure 2. Schematic Layout of the Fuel Cell Powerpla and Metal-Hydride Storage

Table 1. Battery and Fuelcell Specifications

Comparison of Battery and Fuelcell Locomotives		
Parameter	**Battery**	**Fuelcell**
Power, rated continuous	7.1 kW (gross)	17 kW (gross)
Current, rated continuous	76 A	135 A
Voltage at continuous rating	94 V (estimated)	126 V
Energy capacity, electrical	43 kWh	53 kWh
Operating time	6 h (available)	7.5 h
Recharge time	8 h (min)	1 h (max)
Vehicle weight	3,600 kg	2,500 (without ballast)

The hydride storage system stores 3 kg of hydrogen, sufficient for eight hours of locomotive operation at the predicted 6 kW average power of its duty cycle. Hydride subsystem design allows for rapid change-out (swapping) of a discharged bed with a freshly charged unit. Recharging will utilize gaseous hydrogen and has been measured at approximately one hour.

The Mine Safety and Health Administration (MSHA) focused on possible hazards of hydrogen underground, including detailed review of process piping and electrical routing. The assessment indicated a few changes required to meet existing standards and helped to establish new standards for hydrogen-fueled underground mine vehicles.

MSHA measured noise levels (Table 2) of the locomotive under a number of operating conditions, including acceleration (2). Unlike some fuel cell vehicles, our locomotive is very quiet under all conditions. It emanates a pleasant, low frequency purring, and normal conversation can easily be carried out while standing beside the operating powerplant. Consequently the steel-wheel-to-steel-track generated noise will be the most prevalent.

The locomotive was successfully tested and evaluated in two underground mines, one an experimental mine, the other a gold production mine (27 level, 4,000 feet underground). Pulling upwards of 20 tons, the locomotive performed flawlessly logging over 60 hours of runtime. Prior to underground testing a complete documentation package was approved including an extensive risk assessment and site-specific safety evaluations. A large portion of this regulatory approval will set the basis for future fuel cell-powered underground mining vehicle specifications.

Table 2. Average Recorded Sound Levels

Average Sound Levels for the Locomotive		
Location / Condition	**dBA***	**Linear****
Operator Position/Traveling Forward, Run #1 (Full Throttle)	75.3	80.1
Operator Position/Traveling Forward, Run #2	76.6	85.1
Operator Position/Traveling in Reverse, Run #1 (Full Throttle)	76.6	85.2
Operator Position/Traveling in Reverse, Run #2	76.2	82.2
Operator Position/Idle	74.4	81.2
6 Inches from Blower on Right Side/Idle	78.9	85.3
6 Inches from Top Vent on Right Side/Idle	80.8	84.3
6 Inches from Control Panel on Left Side/Idle	79.5	84.0
1 Foot in Front of Locomotive/Idle	75.3	81.9
Background Near Area of Tests	73.4	78.3

* Sound Level using an "A-weighted" network
** Sound Level using an unweighted network (flat response)

Conclusions

The problems of vehicle emissions and noise have negative economic consequences for underground vehicle applications. Fuel cells coupled with reversible metal-hydride storage, by solving these problems, offer cost offsets - higher productivity and lower operating costs - that can make underground fuel cell-vehicles cost-competitive sooner than surface applications. Our hydride-fuel cell locomotive, like the battery version, is a zero-emissions vehicle. However, the fuel cell locomotive has greater net power, greater energy storage, higher gravimetric energy and power density, higher volumetric power density, and substantially faster recharging. Because weight is not an issue, safe and compact metal-hydride storage is an ideal storage technology for underground locomotive applications.

References

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Presentations

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